Quick-Starting Fuel Processors - A Feasibility Study

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Objectives

- Determine the feasibility of starting a practical fuel processor in 60 seconds or less.
- Identify technical barriers that limit the fast-start capabilities of fuel-flexible fuel processors.

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year R,D&D Plan:

- I. Fuel Processor Startup/Transient Operation
- M. Fuel Processor System Integration and Efficiency
- L. Hydrogen Purification/Carbon Monoxide Cleanup

Approach

- Working with multiple national laboratories, universities, and commercial organizations, design a gasoline fuel processor that can meet DOE's performance targets.
- Develop a start-up strategy that will enable the fuel processor to deliver >90% of its rated hydrogen production capacity in 60 seconds or less.
- Demonstrate start-up performance of key fuel processor components and the performance of the integrated fuel processor in laboratory tests.
- Analyze test results to evaluate performance.

Accomplishments

- Designed a laboratory-scale (10 kWe) fuel processor.
- Provided project partners with component specifications for fuel processor fabrication.
- Modeled fuel processor, demonstrating the feasibility of an 84% steady-state efficiency and a 60-sec start-up time.

Future Directions

- Demonstrate 60-sec start-up in a fuel processor that delivers 90% of rated hydrogen capacity.
- Demonstrate greater than 80% fuel processing efficiency under steady-state operation.
- Analyze data for processor performance, start-up fuel consumption, and process limitations.

Introduction

To be capable of start-and-go driving, all propulsion power components must be operational shortly after the driver turns the key. For a fuel cell vehicle with an on-board fuel processor, this means that the fuel processor must produce and deliver sufficient hydrogen to the fuel cell on this basis. This requirement is relaxed somewhat in a hybrid vehicle operated by a fuel cell and a battery, since the battery can provide initial traction power while the fuel cell system warms up to its operating temperatures.

For the on-board fuel processor, the Department of Energy has targeted start-up times of 60 seconds and 30 seconds (from ambient temperature of 25°C) for the years 2005 and 2010, respectively. Considering the significant mass of the fuel processor, some of which must be heated to several hundred degrees centigrade, the start-up process warrants attention at the early design stage. Reducing the thermal mass will reduce the energy needed (fuel consumption) during start-up, and a consistent, reproducible, and durable fuel processor that can meet the start-up time targets can be ensured through suitable heating strategies.

Approach

A subscale (10-kWe) fuel processor system will be designed, fabricated, and tested in the laboratory to demonstrate that it can convert gasoline and deliver 90% of its hydrogen production capacity in 60 seconds. The fuel processor will be designed for a steady-state fuel processing efficiency (defined as the lower heating value of hydrogen produced divided by the lower heating value of the gasoline feed) greater than 80%. The experimental unit will be thermally integrated and will include several heat exchangers and air and water injection ports.

This is a collaborative project with contributions from Los Alamos National Laboratory (LANL), Oak Ridge National Laboratory (ORNL), Pacific Northwest National Laboratory (PNNL), and a number of universities and private organizations. The fuel processor will be assembled and tested at Argonne National Laboratory (ANL).

Results

A laboratory-scale 10-kWe fuel processor has been designed to operate at an efficiency of greater than 80%. The fuel processor (see Figure 1) consists of an autothermal reformer (ATR) followed by a 4-stage water-gas shift (WGS) reactor and a 3-stage preferential oxidation (PrOx) reactor. A total of 6 heat exchangers are located in the reformate flow path to cool the reformate gases. The cooling needed before the fourth WGS stage is achieved by injecting liquid water. The higher steam concentration improves the low-temperature shift conversion. HE1, the heat exchanger between the ATR and WG1, is a microchannel heat exchanger designed and fabricated by PNNL to handle a heat load of 3.6 kW. The five other carbon foam heat exchangers are designed and fabricated by ORNL. The preferential oxidation reactor zones are designed and fabricated by LANL.

Table 1 lists some of the key design and operating parameters of the fuel processor. At the rated capacity

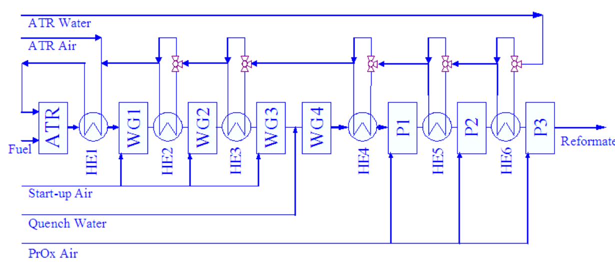

Figure 1. A Simplified Schematic of the Fuel Processor

Table 1. Design and Operating Point for the 10-kWe Fuel Processor to be Studied

	ATR	WG1	WG2	WG3	WG4	P1	P2	P3
GHSV, per hr	74K	66K	41K	22K	13K	37K	37K	37K
Inlet Temperature, °C		375	350	300	280	140	140	100
Exit Temperature, °C	775	440	367	310	287	220	188	113
O/C Ratio (at Inlet)	0.75							
S/C Ratio (at Inlet)	2.1				2.3			
H_2 at Exit, %-wet	31.8	37.5	39.1	39.9	39.7	38.7	37.7	37.5
CO at Exit, %-wet	9.7	4.0	2.5	1.6	1.0	0.3	0.1	10 ppm
H_2O at Exit, %-wet	23.9	18.1	16.6	15.8	16.9	16.9	17.2	17.2

of 10 kWe, the overall gas hourly space velocities (GHSVs) in the ATR, WGS (combined), and PrOx (combined) are 74000, 6200, and 12300 per hour, respectively. With these catalyst loadings and operating conditions, the model predicts a fuel processing efficiency of 84%. This value assumes no heat loss and that sufficient heat is available from the anode gas burner to vaporize and heat fuel vapor to 150°C and supply liquid water at 90°C.

Table 2 lists the mass of each of the catalyst zones and the heat exchangers in the 10-kWe experimental fuel processor and their respective average temperatures at the steady-state design point. Based on these masses and temperatures, the minimum fuel energy that will be needed to heat up the fuel processor components during start-up from 25°C is 1.5 MJ.

The start-up strategy relies on the ATR component reaching its operating temperature very quickly. Assuming this can be achieved by operating at a high O/C ratio [ratio of oxygen (from air) to carbon in the ATR feed stream] without damaging the catalyst, the resulting reformate (containing combustible gases H2, CO, and light hydrocarbons)

Table 2. Masses of Components in the Experimental Fuel Processor (10-kWe) and the Minimum Energy Needed to Reach Operating Temperatures

Component	Mass, g	Average Temperature, °C
ATR	150	725
WGS-1	235	400
WGS-2	375	360
WGS-3	690	300
WGS-4	1150	285
PrOx-1	290	180
PrOx-2	290	165
PrOx-3	290	110
HE-1	1100	575
HE-2	586	395
HE-3	586	334
HE-4	943	214
HE-5	943	180
HE-6	943	144
Minimum Fuel Energy Needed per Start from 25°C, MJ		1.5

will be oxidized just ahead of WG1, WG2, and WG3 by injecting controlled amounts of air, as shown in Figure 1. The start-up strategy requires that only the ATR and the first three zones of the shift reactor are brought up to temperature. The PrOx units have been sized to compensate for the higher CO (up to 4%) from the shift reactor during start-up.

Figure 2 shows the temperature progression predicted from the simulation of a start-up algorithm. The ATR temperature reaches 800°C in less than 2 seconds, and temperatures in WG1, WG3, and P3 are close to their design temperatures in 60 seconds. The sharp rise in ATR temperature seen in this simulation is considered somewhat risky for catalyst durability. Even though the strategy does not call for heating HE1, the high-temperature reformate from the ATR does contribute to its warm-up. Figure 3 shows that the hydrogen production rate reaches ~90% of capacity within 60 seconds. Experimental measurements

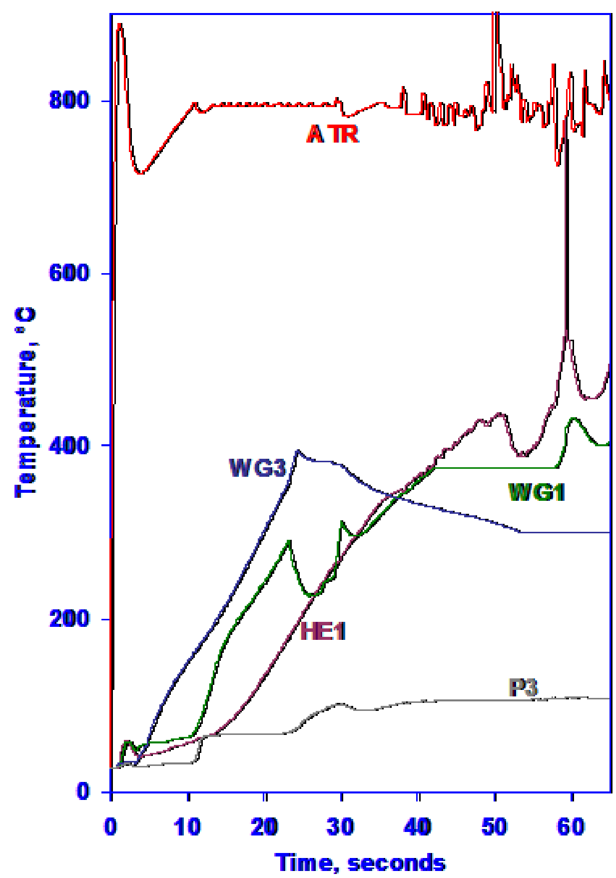

Figure 2. Simulation of a Start-Up Algorithm Showing Temperature Progression of Selected Components (at exit)

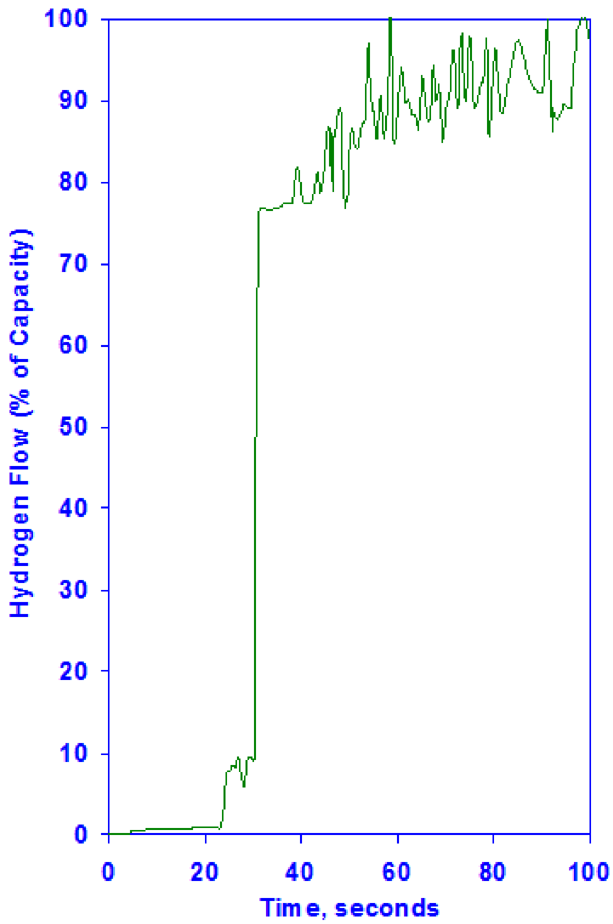

Figure 3. Simulation of a Start-Up Algorithm Showing Hydrogen Production During the Start-Up Period

will be used to develop an acceptable fast-start algorithm.

Conclusions

Argonne National Laboratory is leading a collaborative effort to study the feasibility of fast-starting a fuel processor. A fuel processor has been designed to deliver 90% of its rated capacity for hydrogen in 60 seconds. A model of the fuel processor projects that the targeted start-up goals can be met and that the fuel processor will operate at a steady-state efficiency of greater than 80%. These calculated results will be validated experimentally with the fuel processor being fabricated, and the results will be analyzed to identify technical barriers that limit the fast-start capabilities of fuel processors.

FY 2003 Publications/Presentations

1. C. Pereira, S. Ahmed, S.H.D. Lee, and M. Krumpelt, "Integrated Fuel Processor Development," 2002 Future Car Congress Proceedings, SAE Paper No. 02FCC-161, Arlington, VA (2002).

Special Recognitions & Awards/Patents Issued

1. R. Ahluwalia, S. Ahmed, and S.H.D. Lee, "Method for Fast Start of a Fuel Processor," Invention Disclosure filed with Argonne National Laboratory (2003).

2. S. Ahmed, R. Ahluwalia, and S.H.D. Lee, "Fuel Processor for Producing Hydrogen from Hydrocarbon Fuels," Invention Disclosure filed with Argonne National Laboratory (2003).